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SPACE NETWORK SCHEDULING BENCHMARK: A PROOF-OF-CONCEPT PROCESS FOR TECHNOLOGY TRANSFER

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Summary

This paper describes a detailed proof-of-concept activity to evaluate flexible scheduling technology as implemented in the Request Oriented Scheduling Engine (ROSE) and applied to Space Network (SN) scheduling. The criteria developed for an operational evaluation of a reusable scheduling system is addressed, including a methodology to prove that the proposed system performs at least as well as the current system in function and performance. The improvement of the new technology must be demonstrated and evaluated against the cost of making changes. Finally, there is a need to show significant improvement in SN operational procedures. Successful completion of a proof-of-concept would eventually lead to an operational concept and implementation transition plan, which is outside the scope of this paper. However, a high-fidelity benchmark using actual SN scheduling requests has been designed to test the ROSE scheduling tool. The benchmark evaluation methodology, scheduling data, and preliminary results are described.

Background

The concept of flexible scheduling has been proposed to help meet the Space Network's (SN) anticipated increase in mission support in the late 1990's. The goal of flexible scheduling, which is described in the next section, is increased resources utilization with less manual effort. If SN utilization could be increased 10%, about an additional three service hours per day would be available on each TDRS single access (SA) antenna. This increase provides a total of 24 extra service hours per day, given four operational TDRSs. Scheduling studies have indicated that the flexible scheduling approach will result in increased utilization even if only some customers specify flexibility. [1] Furthermore, designers of many upcoming missions have indicated a desire to utilize flexible scheduling concepts with the SN. [2] Another benefit of flexible scheduling is the reduction in effort required for both customer and Network Control Center (NCC) scheduling operator. [3] For these reasons, the Networks and Data Systems Technology Divisions undertook a detailed proof-of-concept activity to evaluate the flexible scheduling technology as implemented in the Request Oriented Scheduling Engine (ROSE). [4]

A high-fidelity benchmark has been designed to test the ROSE scheduling tool. This benchmark uses real SN scheduling requests and then modifies them into flexible requests for those customers who can take advantage of flexibility. The benchmark evaluation methodology and scheduling data are described, as well as how the ROSE tool was tailored and used in the proof-of-concept required by NCC operations. ROSE is a generic scheduling engine and was augmented by the development of two algorithms designed for NCC-type operations, including the lookahead algorithm currently in use in the NCC. Also, a usability test has been defined to specifically test the scheduling system user interface for supporting NCC operational scenarios. Preliminary results of the benchmark functional performance testing are presented.

Flexible Scheduling Request (FSR) Concept

The FSR concept is a candidate for the future Mission Operations Center (MOC) interface to the SN. The concept has evolved over the years based on experience in mission operations in scheduling both spacecraft activities and shared space network services. [5,6,7,8] The flexible request approach represents a major change in operations concept. Today each customer submits (and resubmits) requests for specific TDRS resources and receives yes/no responses. A large percentage of the rejected requests in the current system are resolved by exercising the users' flexibility through manual coordination. [9] Alternatively, requirements for space network service requests can be specified in an FSR featuring:

- Flexibility - variable start times, duration, or optional resources
- Repeatability - number of service repetitions and their periods
- Alternatives - primary and backup services
- Constraints - orbital events such as orbits, TDRS antenna view periods, spacecraft day, equator crossings, etc., relationships with other services or requests, or calendar events.

In flexible request scheduling, the user considers all service options and codifies flexible service windows in the request. The space network scheduling system then has more information upon which to base scheduling decisions, increasing the likelihood of successfully satisfying the request. The format for this new scheduling information may be an extension of the Schedule Add Request (SAR) or a new language-based interface.

A key benefit of the FSR concept is the shift of a significant conflict resolution effort from humans to computers. The FSR operations concept minimizes request-response iterations between the network scheduling system and the customer since multiple events can be scheduled from a single request (using repeatability specifications). Also, backup events can be identified and substituted in cases where the primary service is unavailable. The FSR concept supports automated conflict resolution strategies, since tolerances in start times and duration are provided. More events are scheduled, supporting more effective resource utilization. The time to generate a week's worth of schedules can be reduced to hours instead of days.

Proof-of-Concept Evaluation Criteria

For NCC Operations, the goal is for a scheduling tool with built-in flexibility to support an evolving and diverse mission support load without increasing operational complexity and cost. The ROSE scheduling tool is proposed as such a tool. NCC Operations developed a high-fidelity benchmark as a criteria against which to evaluate the scheduling tool. This benchmark must prove that the ROSE scheduling tool performs at least as well as the current scheduling system while providing a significant improvement in SN operational procedures. The SN schedule produced by ROSE must be at least as good in terms of fulfilling customer requests as that produced by the current system. In addition, the process by which the final schedule is produced must show a measurable improvement over the current process, including processing time. The human intervention required by the current process is predicted to be the true bottleneck in scheduling customers in the late 1990's time frame. Therefore, the most important evaluation criteria for a new scheduling tool is the improvement that it can provide to the overall scheduling process in reducing the time consuming human interchanges.

Since NCC Operations will emphasize the scheduling process improvement in evaluating any new scheduling tool, the criteria against which ROSE will be measured consists of computer processing time and manual intervention involved in the total scheduling process. The analysis must go beyond a comparison of computer processing time for a single schedule period based on priority processing. It must be inclusive of the human and computer interfaces between the scheduling personnel at the NCC and those at each customer scheduling facility. The benchmark effort has been, and will continue to be, an effort to determine these measurements.

ROSE Benchmark Proof-of-Concept

The approach for the proof-of-concept involves two phases. In the first phase, the goals are to:

- Perform a high level assessment of ROSE forecast scheduling ability compared to the Network Control Center Data System (NCCDS)
- Verify that ROSE allocates resource appropriately, and
- Compare the computer run times required to generate a forecast schedule prior to manual conflict resolution.

Although the NCC scheduling functions involve additional capabilities, (e.g. request validation, schedule dissemination) resource allocation is the primary function and clearly the most complex. Therefore, our efforts focus on that capability. The resource allocation verification in conjunction with the ROSE usability testing will provide the basis for evaluation of ROSE as a scheduling tool from an NCC perspective. This phase will be referred to as "Phase I: Schedule Comparison and Resource Allocation Verification."

In the second phase, the emphasis is on demonstrating improvements in operational procedures and evaluating ROSE from a SN customer perspective. ROSE has potential for significantly reducing the time required to perform the current NCC forecast schedule generation process because of its support of flexibility. This benefits both NCC and customer operations. In this phase we will quantify the reduction. Also, since ROSE capabilities involve much greater degrees of flexibility than the current NCC, it is important that the customer understand how they can effectively use these new flexibility options. The customers' evaluation of the resulting schedule is key to the overall assessment of ROSE. This phase will be referred to as "Phase II: Procedure Improvement and Flexibility Analysis."

For Phase I we describe the process, the environment in which the process was performed, the schedule and related data utilized, and finally summarize preliminary results. Space doesn't allow a similar description of Phase II, however we will highlight the new features and indicate status.

PHASE I - Schedule Comparison and Resource Allocation Verification

The Process. The key drivers for devising the resource allocation verification process are time and realism. Our goal is to perform a high level comparison of schedules and computer run times, as well as to check that ROSE schedules SN resources without conflict. An in-depth detailed verification would take on the order of several months and require skilled test personnel. This type of testing will be performed in more formal testing phases if ROSE is selected as an NCC scheduling system. Realism is key because we want to focus the evaluation on the most common types of resource conflicts encountered, while still ensuring all resources are allocated properly. The data flow for the Phase I process is illustrated in Figure 1. Shaded boxes indicate completed activities at the time of publication.

Both drivers can be addressed by using operational SARs and related data for an NCC forecast week and submitting them to both the NCCDS and to ROSE. The resulting schedules will be compared in terms of number of events scheduled and minutes of support scheduled. Currently, the operational SARs express flexibility in event start time and SA antenna, therefore, it is possible to generate different conflict-free schedules. However, one schedule may better satisfy the SN customers.

While this comparison provides a foundation for evaluating schedules and run times, an additional step is required to verify ROSE resource allocation. The ROSE scheduled events will be formatted

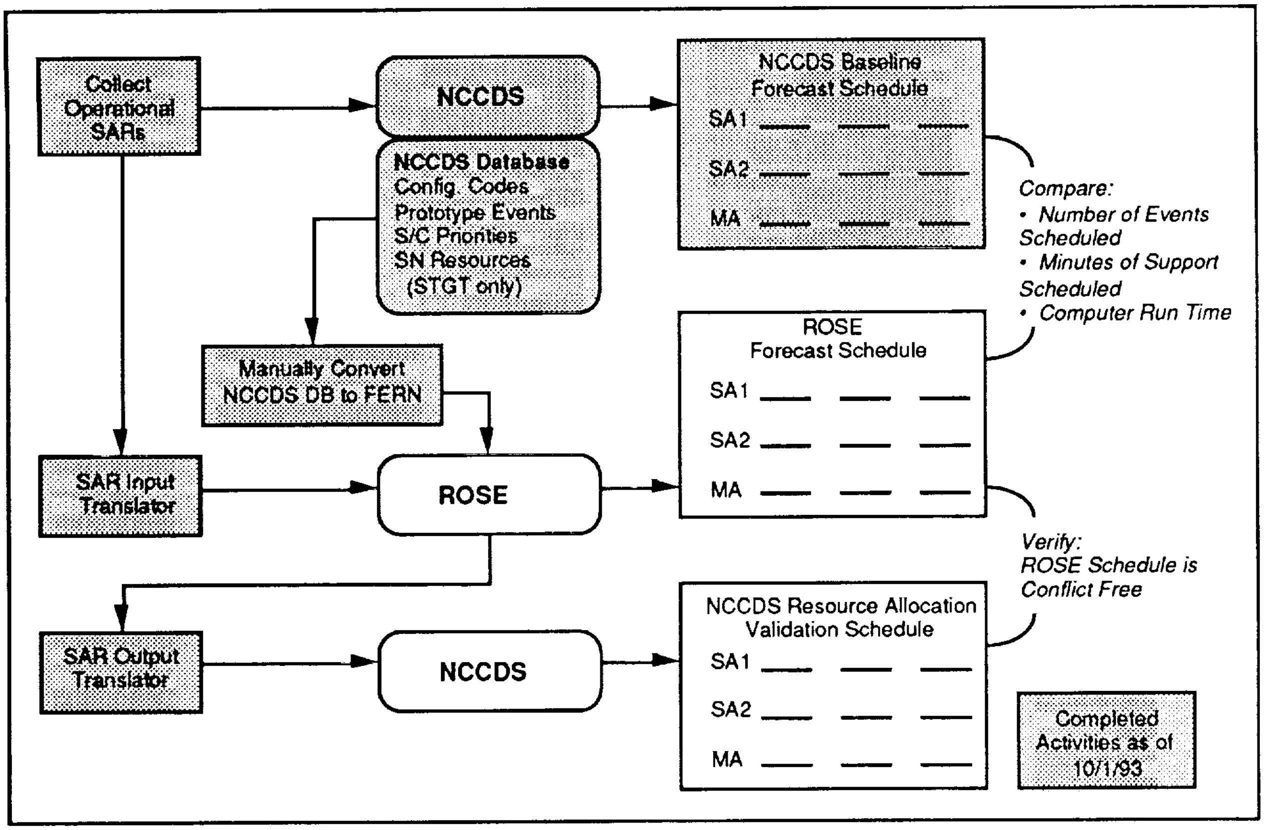

Figure 1. Phase I Process Overview

into specific SARs, without start time flexibility, and submitted back to the NCCDS. Another NCCDS forecast schedule generation run will be performed to determine if ROSE scheduled any requests in conflict based on NCCDS resource allocation rules.

The Environment. Utilizing actual SARs requires that the entire process be performed in a classified environment. The NCCDS baseline schedule and the resource allocation verification schedule run will be performed within the NCC. A SUN Sparcstation will be installed in the NCC to support the ROSE benchmark evaluation effort. The results of the evaluation will be presented in an unclassified manner.

To provide an accurate comparison of the NCCDS baseline schedule and the ROSE generated schedule, the comparison is made for running all SARs together in one schedule generation run. The NCCDS baseline schedule prior to any manual conflict resolution is the result of that run.

In the NCCDS, the resources utilized in the schedule run are dependent on the ground terminal that supports the available TDRSs. Since the time frame in which a new NCC scheduling system would be implemented is likely to be after the Second TDRS Ground Terminal (STGT) is operational, all TDRSs will be assigned to STGT for all of the Phase I schedule runs.

Schedule and Related Data Collection

It was necessary to carefully choose and coordinate the SARs, configuration codes, prototype events, and spacecraft priority list for all of the tests. To obtain the operational SARs, a forecast week was selected that included a shuttle mission to address a significant scheduling workload. Coordination with the SN customers was necessary in gathering mission scheduling data. The SARs were logged by the NCCDS Test System (NTS) for the test. Compatibility tests were performed between the NTS and ROSE to ensure that they could reliably exchange the SAR data. The NTS will be used to extract the SARs and to submit the ROSE generated SARs to the NCCDS for the resource allocation verification step.

Configuration codes and prototype events are specified in the SARs. Copies of these were provided to ROSE to ensure that the same resources are requested in all schedule runs. The same spacecraft priority list will also be used in all schedule runs in accordance with operational procedures. The same NCCDS database which contains the configuration codes, prototype events, and spacecraft priority list will be used for the NCCDS schedule run to verify ROSE resource allocation. The NCCDS baseline schedule was generated using this database, after all validated SARs were received for the selected forecast week.

The boundary between the active and forecast period was also addressed. Some of the active period events start late in the day on the last day of the active period and overlap into the forecast period. These events were included in the forecast period schedule data collected for the tests.

Data Preparation for Input into ROSE

The first challenge from the ROSE perspective was deciding how to represent NCC information in ROSE's Flexible Envelope Request Notation (FERN). [10] This information falls into the following general categories: resources for allocation, scheduling ground rules, and requests. Scheduling ground rules include specifications for setup buffers on resources (i.e., the time required between uses of a resource), duty factors on the Multiplexer/Ddemultiplexer (MDM) and Statistical Multiplexer (Stat Mux), and restrictions on the choice of TDRS antenna within an event.

Scheduling Resources. In order to schedule the SN, both communication services and TDRS antennas must be allocated, although there is a very strong tie between them. For Multiple Access (MA) services, one service equates to one antenna. However, multiple SA services may be scheduled on a single physical antenna, provided all services are for the same customer (since the antenna can point to only one spacecraft at a time). Customers request services. However, once one SA service is assigned to a customer, the remaining SA services on that antenna can not be assigned to any other customer. Therefore in requesting an SA service, the customer is in effect requesting an SA antenna. However, due to equipment failures, not all SA antennas support all services. The NCC maintains equipment status, and therefore must insure that a customer is assigned to an SA antenna capable of supporting the services requested.

The definition of the resources within ROSE accounts for this close coupling of two different resource types (antennas and services). To do so, the physical antennas were defined as the most primitive resources. Each service was then defined as a pool of physical antennas capable of supporting that service. In order to insure that all SA services for an event were assigned to the same SA antenna, combinations of services were defined as resources that list all of the physical antennas capable of supporting all services in that combination. The customer then specifies a service combination as a requested resource. ROSE assigns the event to a physical antenna listed in the service combination definition. This physical antenna is no longer available to other requests for the time frame requested. However, this strategy does allow multiple services from the same request to be assigned to the same physical antenna.

Other resources, such as interface channels and duty factors, are more independent and made a fairly simple transition into FERN and ROSE. Requests for certain customer interface channels do imply a need to request certain duty factors, however this relationship impacts the original request generation and not the scheduling process. Interface channels are simple capacity resources; customers request a single unit of each interface channel and they are either available or not. Duty factors are consumable/renewable resources, where customers request multiple units corresponding to their required maximum bandwidth. The combined bandwidth of all services from all customers cannot exceed a certain threshold.

Scheduling Ground Rules. The majority of the scheduling ground rules were worked into the resource definitions. The duty factor constraints were implemented as consumable/renewable resources as mentioned above. Resource setup buffers specify the amount of time required between each use of a resource for reconfiguration for the next support. The SN uses two setup buffers for many resources, one where the next use of the resource is in another event (external buffer), and one within the same event (internal buffer). FERN has an option within the resource definition for specifying a minimum gap between each use of the resource, but is incapable of expressing internal event buffers. Since all external buffers are equal to or slightly larger than setup buffers internal to an event, only the external buffers were implemented. Not using internal buffers was insignificant to the benchmark, since the likelihood of an event containing back-to-back use of a resource within the internal buffer is improbable, given the experience of current SN customers.

There are additional ground rules that specify that all services within an event must be on the same TDRS, and that if a service stops and restarts within an event, the same antenna shall be used for each instance of the service. These restrictions were incorporated into the scheduling algorithm.

The NCC Lookahead Algorithm. The NCC lookahead algorithm uses a conflict avoidance strategy. The basic principle is to examine the placement options of an event, and schedule it in the spot that is least likely to create a conflict with a lower priority pending request. Figure 2 illustrates the logic flow as implemented in ROSE.

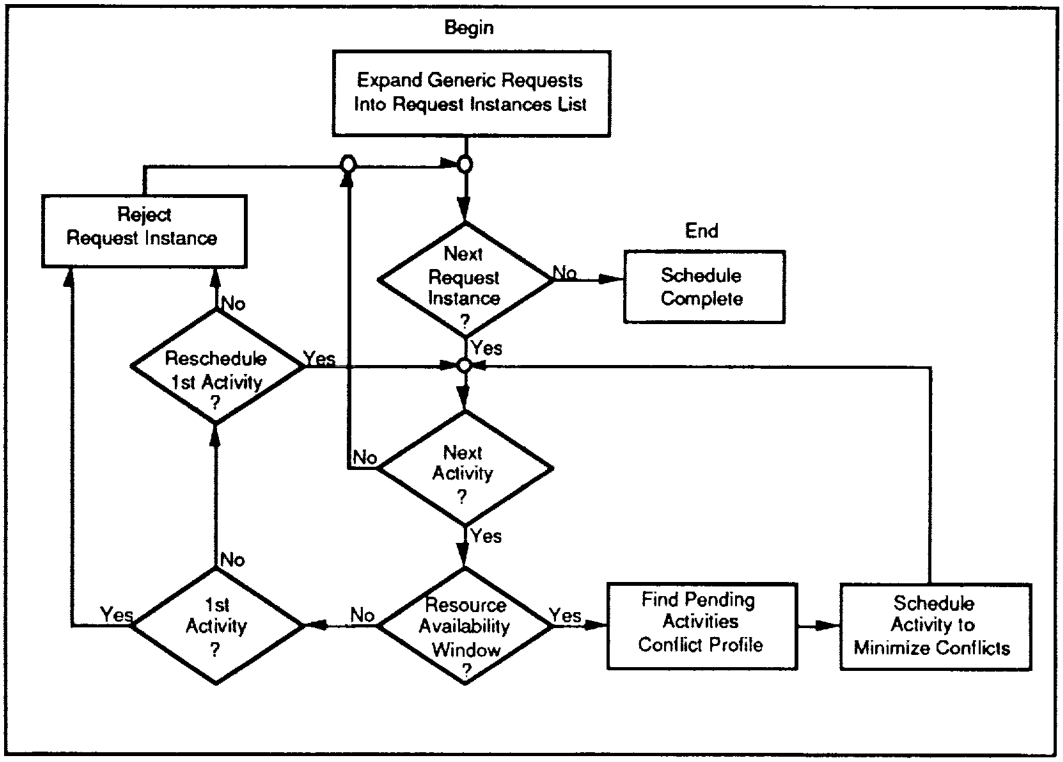

Figure 2. Lookahead Algorithm Logic as Implemented in ROSE

The lookahead algorithm implemented in ROSE, has some subtle differences with the NCCDS implementation. The NCCDS version looks for potential conflicts across services; the ROSE version looks for them across physical antennas. It was determined that this difference would have no impact on schedule outcome. The NCCDS version selects the best location for an event based on the combined potential for conflict across all services in the event. The ROSE version selects the best location for each activity (or service) individually. In flexible requests, it is possible to have more than one activity per event, therefore the best location for the event is not guaranteed. However, for Phase I, where the requests are relatively inflexible, there is a one-to-one correspondence between activities and events and no impact should be seen.

Other differences occur in the minute details of the implementation. These include differences in step size when sliding the start time around within an open window, and differences in the size of the weighting factors in computing a conflict sum for each start time and resource option. In both implementations, potential conflicts with the next highest priority request are weighted more heavily than potential conflicts with the very lowest priority request. Also, potential conflicts on resources that are in higher demand are weighted more heavily than potential conflicts on infrequently used resources. The ROSE implementation took advantage of a ROSE feature that calculates current resource utilization, so that the resource weights can be adjusted dynamically.

Requests. The SN services are grouped as an event in a SAR. However, FERN structures its requests hierarchically, as shown in Figure 3. The generic structure specifies repetition instructions, the activity specifies a sequence of steps and the duration of each step, and the step specifies the resources that are required for that period.

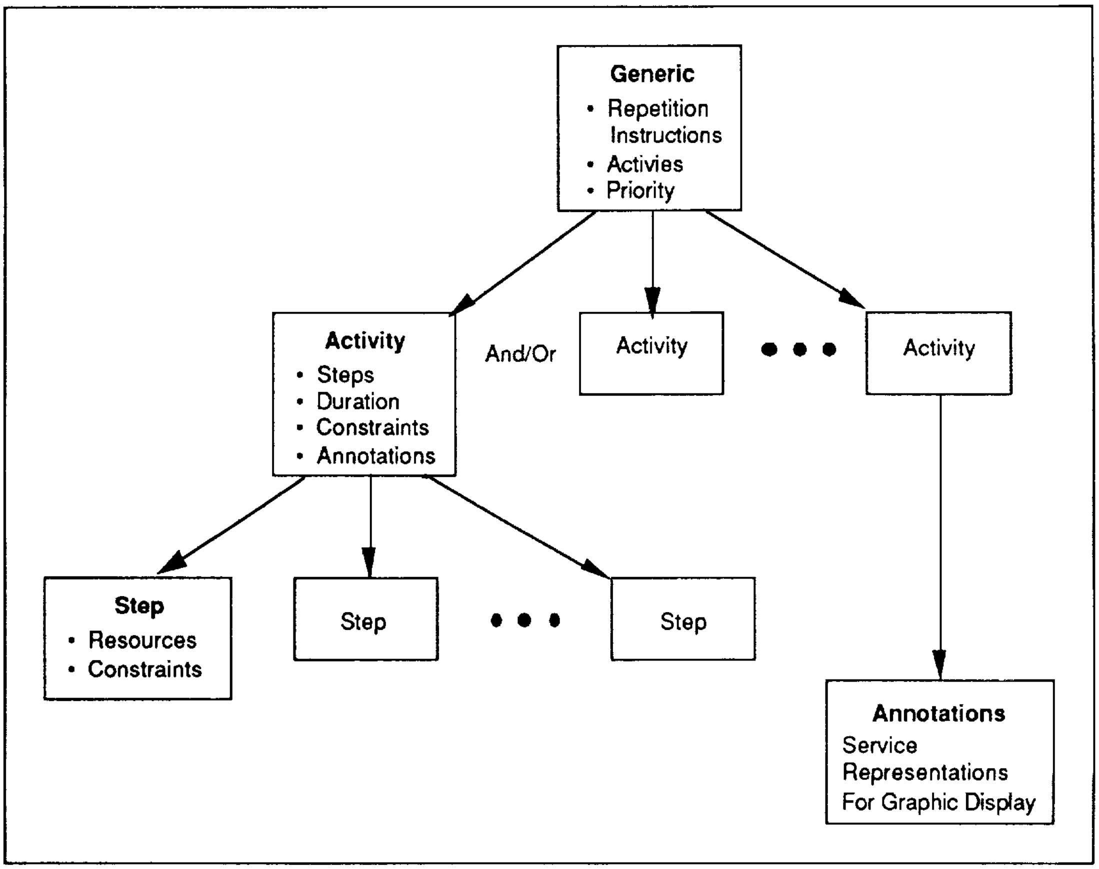

Figure 3. FERN Structure

Steps within an activity are strictly sequential, whereas SN services specified in a SAR typically overlap. Current NCC SARs require the start time of all services to be fixed with respect to one another. This restriction allows the time slicing of the event when converting to FERN. Whenever a service either starts or stops, a new step is defined. Steps then list all resources required for all of the services that are ongoing at that time. For example, an event composed of SSAF, SSAR, and Tracking services, would be represented by an activity with four steps as shown in Figure 4. SA services are time sliced within the activity, however, they always follow the same order (i.e., forward, return, tracking). Thus the combination of FERN activities and steps represent current SN events with services being time sliced among the steps.

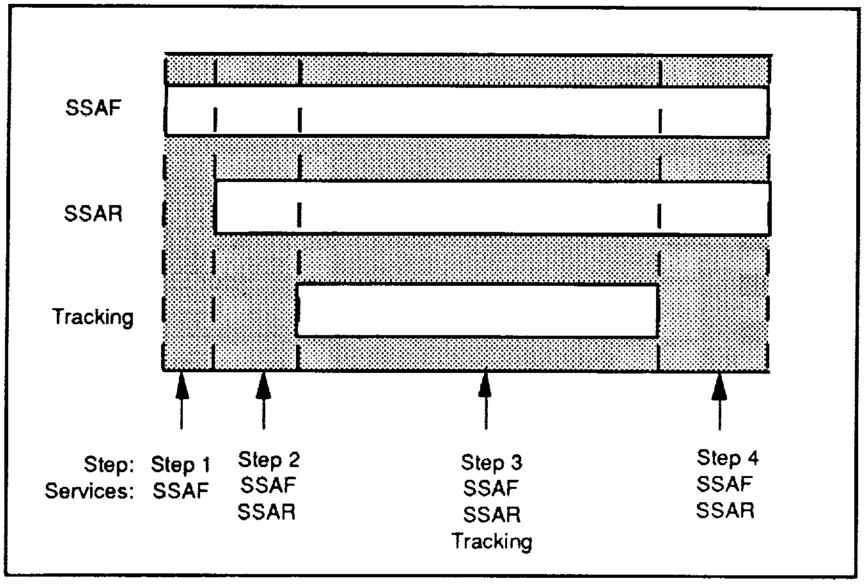

Figure 4. Time Sliced Event Represented in FERN

SAR Input Translator. A SAR translator, was written in the Unix interpreted language AWK. This translator reads in the SAR and reformats it into FERN using the time slicing methodology. Since current SARs are non-repeating, the FERN requests will also be unique, with one generic composed of one activity for each SAR. Each generic and activity is labeled by customer and SAR message id. Each step name lists the customer, message id, and all configuration codes supported during that step. Another FERN structure called an annotation, describes each configuration code. The information in the annotation is not used by the scheduling logic, but only by the display system. Annotations permit services to be displayed as a whole, and not time sliced into multiple steps.

The configuration codes specified in the SAR contain important information concerning requested resources. Since configuration code definitions are in the NCC database, a configuration code database was built for the SAR translator. The SAR translator database is significantly smaller than the NCC configuration code database since it includes only that information required to support resource allocation and only contains those configuration codes actually used during the test week. The SAR translator also references the list of the mission priorities. These are the default priorities inserted into the FERN requests. However, some users had several critical requests that were given a higher priority. These request priorities will be manually modified in the FERN requests. After all SARs are run through the SAR input translator, separate FERN request files will be created for each customer. The only other file needed for the Phase I test is the file describing the SN resources to be allocated. A schedule can then be run using the lookahead algorithm.

SAR Output Translator. The ROSE output schedule is to be submitted back to the NCCDS to verify that ROSE does not inappropriately schedule any requests. The ROSE output schedule must be translated back into the SAR format. Another translator has been developed for this purpose.

The resulting SARs should express no flexibility at all, since they represent scheduled events assigned to specific resources. However, the SAR format does not directly express all required resources; some resources are specified in the configuration codes. The SAR output translator determines the configuration codes used by each event and references them in the output SAR. Unfortunately, most configuration code definitions express flexibility in the antenna choices. If the NCCDS were to choose a different antenna than what ROSE actually chose, the change in one event could cause a ripple effect and produce a different schedule. However, it appears that the NCCDS allocates antennas in numerical order. The resources in FERN can be listed in a similar manner, so that the search pattern in both systems should be the same, and result in the same assignments. If this strategy fails, however, new configuration codes must be defined with very specific resources, and the SAR output translator can be set to reference these new codes.

Phase I Preliminary Results and Status

As of October 1, 1993, we have completed the NCCDS baseline schedule and the description of the result follows. The ROSE schedule is expected to be run later in October after the host workstation is completely installed and procedures are completed for handling classified data.

The forecast week selected was September 13-19, 1993 (256/00:00:00 - 262/23:59:59 Z). The seven day operational forecast process for this week took place beginning on August 30, 1993. We extracted the SARs on August 31 and performed the NCCDS baseline schedule run on September 1st. The NCCDS baseline schedule run included 1028 unclassified SARs and took just over 45 minutes to complete. We measured the primary and secondary resource scheduling separately. Primary resources are the SA and MA Forward (MAF), and start time tolerances are used to schedule these resources. The STGT era secondary resources used in this schedule run were the MA Return (MAR), customer interface channel, MDM bandwidth, and Stat Mux bandwidth.

Table 1 summarizes the initial result of the NCCDS schedule run for the unclassified customers on STGT by order of spacecraft priority before any conflict resolution was applied. The declined SARs were due to conflicts on the following resources:

- 90% - SA or MAF Conflict
- 10% - MAR Limitation
- <1% - User Interface Channel Conflict (one HST request declined)

The set of declined SARs attributable to the MAR limitation are due to the difference between WSGT and STGT resources. TDRS spare was assigned to the third equipment set at STGT which does not support MA, hence, SARs for TDRS Spare MAR were declined. Therefore, in actuality nearly all the SARs were declined due to SA or MAF conflict. The results indicate that lower priority customers who specify tolerances in their requests, like COBE, do increase the likelihood of getting their requests scheduled.

SN Customer	% SARs w/Tolerance	SA Flexibility	% SARs Scheduled	% SARs Declined
GRO Critical	0	Yes	100	0
UARS Critical	0	Yes	100	0
STS - 51	0	No	99	1
HST	< 1	Yes	64	36
GRO	0	Yes	74	26
TOPEX	92	Yes	67	33
EUVE	99	Yes	66	34
UARS	95	Yes	55	45
COBE	70	Yes	89	11
ERBS	99	Yes	54	46
Total			79	21

Table 1. NCCDS Forecast Baseline Schedule Statistics Prior to Conflict Resolution

The NCCDS baseline schedule also had the following computer run time statistics (mm:ss):

Primary SN resources:	03:06
Secondary SN resources:	42:11
Total:	45:17

Similar statistics will be generated for ROSE under Phase I testing in October. Upon completion, we will compare the NCCDS and ROSE schedules and computer run times, and verify that ROSE did not schedule any conflicts. Finally, we will analyze the remaining SARs from NCCDS which were not resolved during the manual conflict resolution process, and any SARs from ROSE which do not get scheduled.

PHASE II - Procedure Improvement and Flexibility Analysis

The Process. As in Phase I, key drivers for devising the process for procedure improvement involve time and realism, so again we will compare NCCDS and ROSE schedule runs using operational SARs and compare the number of events/minutes scheduled and the computer run times. The configuration codes, prototype events and the spacecraft priority list used in Phase II will be the same as that used in Phase I. However, in this phase we will also compare the times to perform the entire procedure to create a forecast schedule including conflict resolution. Figure 5 illustrates the Phase II process.

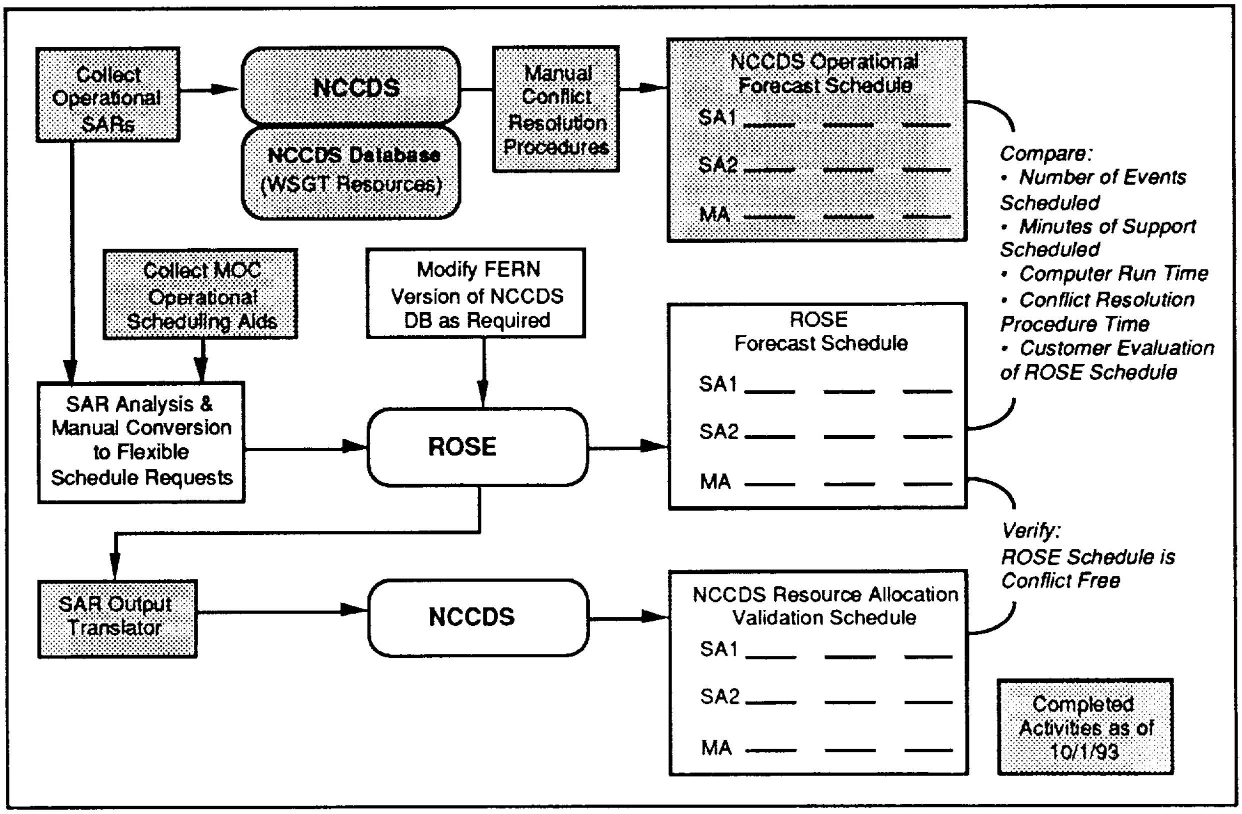

Figure 5. Phase II Process Overview

The NCCDS baseline schedule run for Phase II was performed by the operations personnel. The week selected is the same week as that used in Phase I. When coordinating with each customer for Phase I, we also requested that each customer save the scheduling data used to generate their SARs for support of Phase II. In addition, operational schedule run data, observation notes, and conflict resolution notes were saved. This data will be used to analyze the additional types of flexibility available to the customer.

The additional types of flexibility will be specified as Flexible Scheduling Requests (FSRs) in the FERN language. ROSE will utilize the FSRs to generate a forecast schedule that will be compared to the NCCDS operational schedule run on WSGT resources. At first, it may seem inappropriate to compare an NCCDS schedule run on WSGT resources to a ROSE schedule run on STGT resources. However, it turns out the differences between the resources have minimal effect on the computer and procedure run times. As for the customer perspective, we expect the differences in WSGT and STGT resources to have minimal effect on the use of flexibility. Of course, the difference in resources will be considered when comparing NCCDS and ROSE schedules in terms of number of events and minutes of support scheduled. Finally, ROSE will again generate specific SARs that correspond to the events scheduled using the FSRs. The specific SARs will be scheduled using the NCCDS to provide additional resource allocation verification as with Phase I. The physical environment is the same as Phase I.

User Scheduling Data Collection

In order to translate the original SARs into flexible requests, we need to understand the customers' true flexibility options. We need to understand how they chose where to schedule the requests initially, and how they chose what conflict resolution options were acceptable to them, and which options were preferred over others. We also need to collect any data, such as user antenna views (UAVs), that they may have used in making those decisions. We felt that this data should be collected as soon after the test week as possible, so that the activities were still fresh in the customers' minds, and that files and tapes were not overwritten or deleted.

For this data collection process, we visited all of the GSFC Mission Operations Center (MOCs) and interviewed their scheduling personnel. We also requested that they complete a short questionnaire concerning the conflicts they encountered during the test week, and how they were resolved. By personally visiting each customer, we were able to gain a very clear and detailed understanding of the customer's side of the process for the test week, as well as collect the scheduling aids (e.g., view period data).

The types of flexibility that different customers may have that cannot be expressed in the current SAR are the ability to accept:

- Shorter service duration
- Any TDRS as long as it is in view
- Service start time tolerance
- Wider event start time tolerance
- Different type of service (MA vs SA)
- Moving the contact to another orbit
- Periodically repeating an event

One of the key flexibility concepts is SA service start time tolerance with respect to MA services within same the event. A previous study showed that 71% to 79% of Hubble Space Telescope's conflicts could be resolved using this type of flexibility. [11] The time sliced event representation strategy discussed under Phase I allows flexibility in the relative start times of the different services.

<u>Preparing the FSRs</u>. For Phase II, the request representation we settled on was to have one activity for each physical TDRS antenna requested (versus one activity for each event in Phase I). The generic data structure allows conjunctions of activities, therefore one generic would specify that the

activities in an event must all be scheduled as a unit on the same TDRS. This representation strategy allows flexibility in the relative start times of the different activities.

Most FSRs will be generated manually based on an interpretation of the data collected from the MOCs. For most customers this effort is not expected to be excessive, since they can use the repeatability factor of flexible scheduling, and one FSR can replace many SARs. For those customers who would not use flexible scheduling, the SAR translator can regenerate their specific requests. The SAR translator will likely be modified to also support flexible non-recurring requests. After the FSRs have been created, the customers will verify that they represent acceptable conflict resolution options in the correct order of preference.

Phase II Preliminary Results and Status

The NCCDS operational schedule with WSGT resources and including manual conflict resolution was completed during the forecast week of August 30, 1993, and the results were collected. The number of events at the end of the operational NCCDS schedule run was higher than at the beginning of the week for the initial forecast schedule. This discrepancy is due to additional (late) SAR submissions during the forecast week, and conflict resolutions that include splitting one event into two.

Based on the customer interviews, there were no resolution options exercised that week that could not be expressed in an FSR. Some requests simply could not be satisfied as there were no acceptable resolution options. We are optimistic that ROSE will be able to find conflict resolution options for all requests that were eventually scheduled. The MOCs will also be asked to judge if the options that ROSE found were as good (or maybe even better) than those found manually. We hope to be able to estimate the number of staff hours saved by using flexible scheduling over manual conflict resolution. Table 2 shows the results for the operational schedule after conflict resolution. The column entitled "% Increase over Baseline" shows the additional percentages of requests scheduled over the first run of the forecast schedule before any manual conflict resolution was completed.

Generation of the NCCDS operational schedule had the following computer run times (mm:ss):

Primary SN resources:	06:30
Secondary SN resources:	118:30
Total:	125:00

In addition, 60 hours of forecast schedule operator support time (including wait time for MOC responses to recommended resolutions) were allocated to the manual conflict resolution procedures for the week. The NCCDS preliminary results from Phase II, as compared to the baseline schedule, illustrate the significant increases in scheduled support due to the manual efforts of the forecast operators and customer scheduling personnel. The goal of the flexible scheduling concept is to automate conflict resolution in the schedule run. Similar data will be collected for ROSE during Phase II testing.

SN Customer	% SARs w/Tolerance	SA Flexibility	% SARs Scheduled	% Increase over Baseline
GRO Critical	0	Yes	100	0
UARS Critical	0	Yes	100	0
STS - 51	0	No	100	1
HST	< 1	Yes	99	35
GRO	0	Yes	94	20
TOPEX	92	Yes	100	33
EUVE	99	Yes	98	32
UARS	95	Yes	91	36
COBE	70	Yes	99	10
ERBS	99	Yes	86	22
Total			97	18

Table 2. NCCDS Operational Forecast Schedule Statistics After Conflict Resolution

Lessons Learned to Date

The ROSE evaluation exercise began in May 1993, and in a relatively short time frame we have established a methodology and collected necessary test data for both phases of testing. This same methodology could be adapted to similar technology evaluations by other operational systems or by the NCC for other proposed enhancements.

It was necessary to coordinate the collection of data both in the NCC and the MOCs for the selected forecast scheduling week. The evaluation team held regular status meetings and established close contacts with scheduling and database operations personnel which had several benefits. Many detailed but critical points were uncovered and resolved during the process. Everyone maintained an eye on the evaluation goals and stayed well informed. Close cooperation was needed between government and contractor personnel, as well as between organizational elements. However an end result was the high level of interest in the process and results.

In the process of understanding the scope of scheduling in the NCC, we learned about subtle details of the database with its embedded scheduling ground rules, and the importance of finding an appropriate representation for SARs. The initial conversion of the NCCDS database into FERN for

ROSE input took about a staff month of effort for both analysis and implementation. Representing events as overlapping services had to be carefully addressed in ROSE as there were alternative implementation approaches. Once determined, the implementation of the SAR translator was fairly straight forward, taking only a couple staff weeks.

The lookahead algorithm developed for ROSE was based on the NCC lookahead algorithm. However, the ROSE algorithm takes into consideration the flexibility options which are not part of the NCC algorithm. Further testing and some modifications will be required to fully validate the ROSE algorithm, however the tolerances and open selection capabilities in the current SARs have been successfully tested. Approximately 9 staff months of effort went into the redesign, Ada implementation, and testing of the ROSE algorithm to date.

As we prepare to actually run the validation benchmark test on ROSE, we anticipate that additional testing may be required, in spite of successfully testing individual components of the benchmark. However, we feel we have developed a robust methodology that will be able to adapt to the new lessons we will learn.

Conclusions and Future Work

Technology transfer to operational elements involves the necessity of having to maintain support while upgrading to a new way of doing business. The NCC requires a proof-of-concept benchmark, such as the one we have described, in order to verify the value of proceeding with the time consuming task of transitioning into operations. In addition to the validation of ROSE for producing SN schedules, a usability test of the ROSE user interface is also in process. The ROSE usability test is designed to verify that the interaction techniques provided by ROSE fully support the scheduling tasks performed by scheduling operators. Thus direct evaluation by NCC Operations personnel will assess ROSE utility and drive the need for modifications.

If a new technology proof-of-concept such as ROSE is successfully demonstrated in the testing process the next step is to develop a methodology for transition into operations. A complete operations concept is required, addressing both the NCC and MOC roles and operational procedures in the Flexible Scheduling approach. Since a major change to the NCC requires changes of the customer community, representatives of the SN and the MOCs have been working on a joint paper, "Space Network Flexible Scheduling Enhancements", to identify desired enhancements which will be validated in Phase II. Finally, detailed plans for integration of the new technology into the NCC, and plans for formal acceptance testing will be required.

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